



# The OpenSE Cookbook: A practical, recipe based collection of patterns, procedures, and best practices for executable systems engineering for the Thirty Meter Telescope

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Austin, TX, USA**

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## Agenda

- Introduction
- TMT and MBSE Approach
- Cookbook Principles
- Cookbook Examples

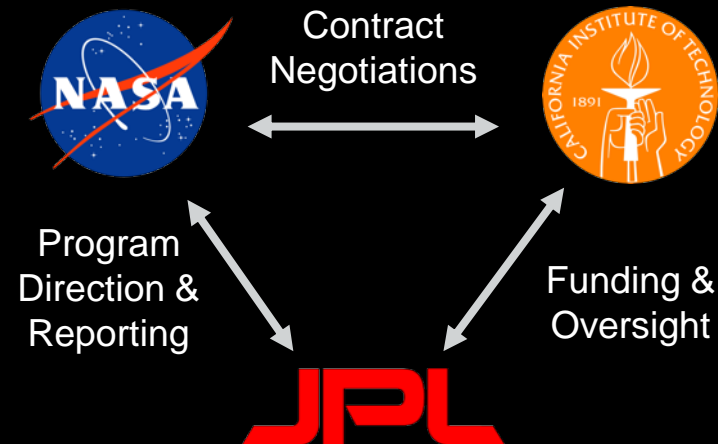


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California Institute of Technology

# NASA Jet Propulsion Laboratory (JPL)



- Located in Pasadena, CA
- NASA-owned *"Federally-Funded Research and Development Center"*
- University-operated
- ~5,000 employees



# Who is Robert?

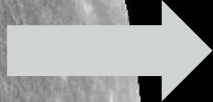


- CAE Project Systems Engineer at NASA's JPL - USA
- Member of INCOSE
- Co-Chair of the OMG SysML Revision Task Force
- Formerly Control System/Software Engineer and Architect at:
  - European Southern Observatory – Germany, Chile
  - CERN – Switzerland/France
  - Siemens Healthcare - Austria
- M.Sc. Computer Science (Austria)





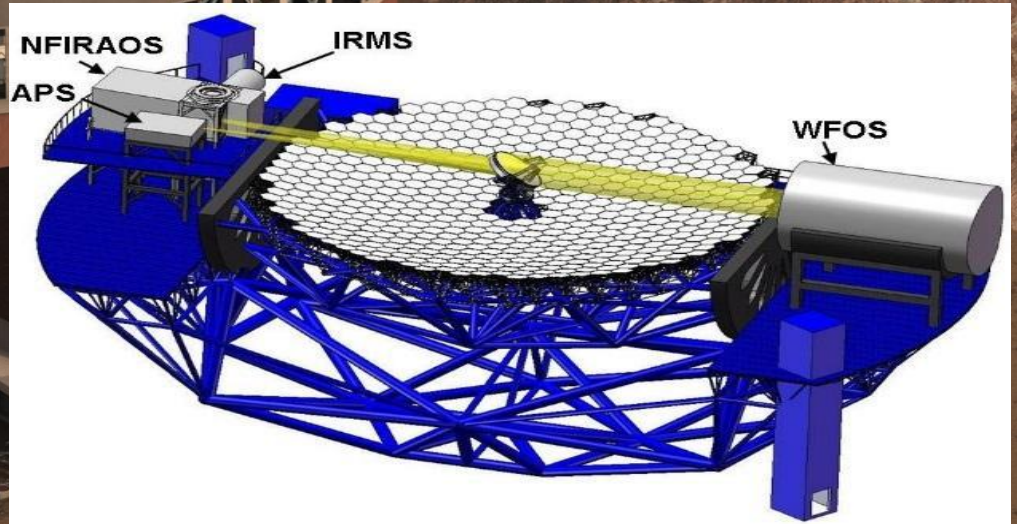
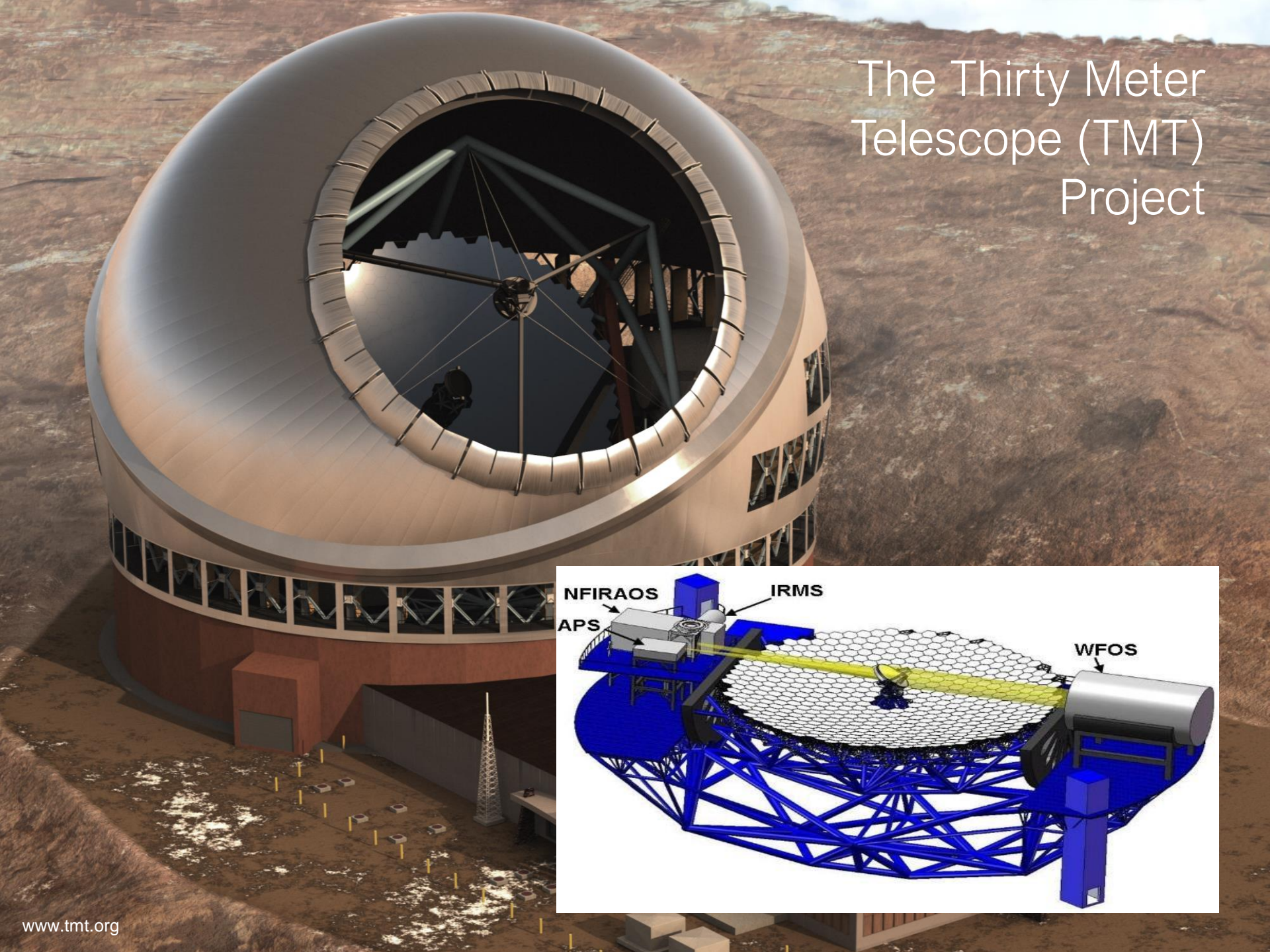
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# The Thirty Meter Telescope (TMT) Project





# TMT applies “Hybrid” Systems Engineering Approach

## Traditional SE

- Clear, defined deliverables
- Easily accessible
- Shallow learning curve
- Simple traceability

## MBSE

- Understanding behaviors of a system
- “Rich” capability to represent complex systems

**Exploit the advantages of each approach**

# TMT MBSE Approach delivers consistent, verifiable engineering products

- Define an **executable SysML model**
- Use the model to **analyze the system design and verify requirements** on power consumption, mass, duration, pointing errors, etc.
- Produce **engineering documents**
  - Requirement Flow Down Document
  - Operational Scenario Document
  - Design Description Document
  - Interface Control Documents
- Use **standard languages and techniques, and COTS tools where practical** to avoid custom software development



# TMT MBSE follows a well defined Modeling Approach

- Object-Oriented Systems Engineering Methodology (**OOSEM**), but with additional activities focusing on building an executable model
- Use case driven model development
- Challenges:
  - JPL is a **supplier** for a number of subsystems of the TMT (the **customer**)
  - Model is used by a number of teams, including TMT


**ESEM = OOSEM + Executability**

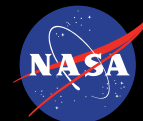
# Executable SE Approach focuses on Key SE Artifacts

- Emphasize executable models to enhance understanding, precision, and verification of requirements
- Executable Systems Engineering Method (**ESEM**) augments the OOSEM activities by enabling executable models
  - ESEM defines executable SysML models that verify requirements
  - Includes a set of analysis patterns that are specified with various SysML structural, behavioral and parametric diagrams
  - Also enables integration of supplier/customer models and analysis



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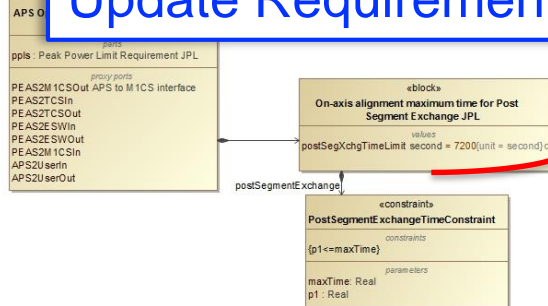
# OpenSE Cookbook addresses Systems Engineering Concerns

- Provides goal oriented guidance using patterns, e.g.
  - How-to Verify Requirements
  - How-to Roll-up Technical Resources
- Driven by Systems Engineering Workflows
- Enables combining patterns into more complex recipes
- Demonstrates how to build system models with available tooling - How/where do I start?
- Includes known usages in TMT production model as reference
- Commoditizes Executable Systems Engineering

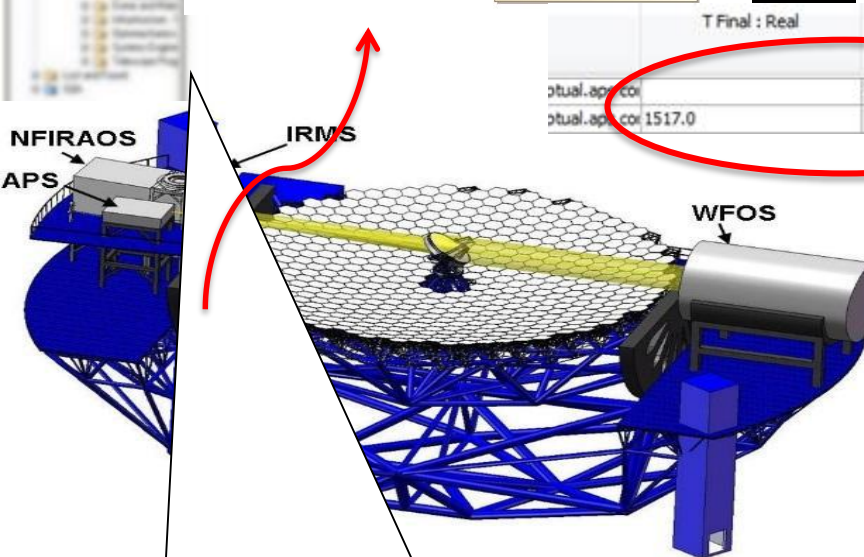
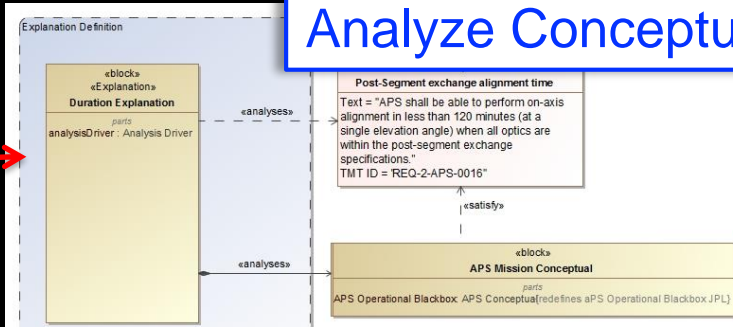


# TMT Analysis workflows drive the OpenSE Cookbook

## Update Requirements 2

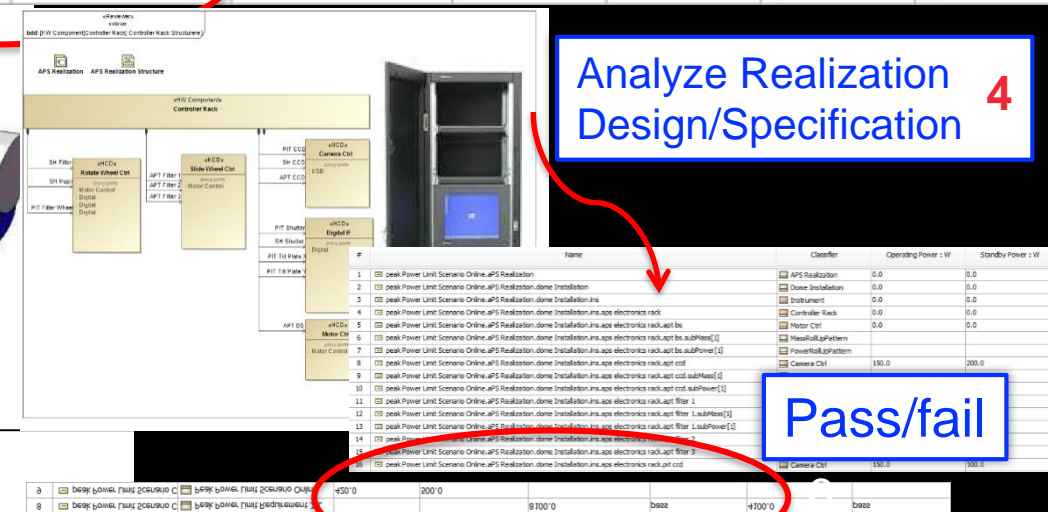


## Analyze Conceptual Design 3



	T Final : Real	Post Seg Xchg Time Limit : Second	Post Segment Exchange : Post Segment Exchange Time Constraint	Off Axis Measurement Steps : Integer	Off Axis Map Points : Integer	RB Dlt : Integer	Phasing Dlt : Integer
actual.ap.col	1517.0	7200.0	pass	6	7	45	20

## Analyze Realization Design/Specification 4



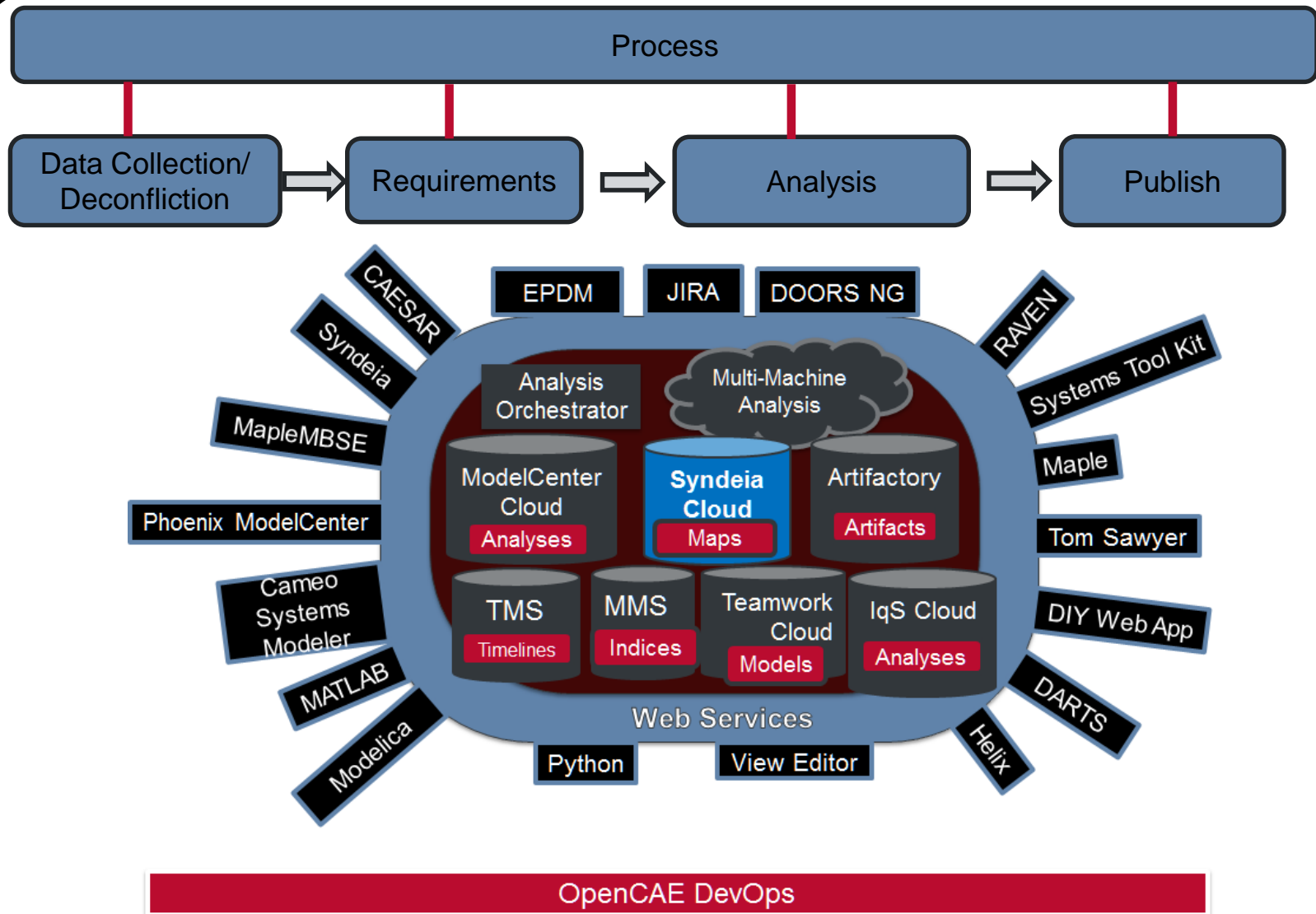
Pass/fail

## Produce Engineering Documents 5

## Change request 1

Max duration Post-segment exchange: 7200s 5000s  
Number of exposures of 45s 4 6  
Max peak power consumption in dome: 8.5kw 8.1kw  
Number of motors with 50W 10 12

# JPL/CAE Systems Environment provides integrated Life-Cycle Support



JPL develops requirements for Systems Environment (tooling) through Case Studies

For Example:

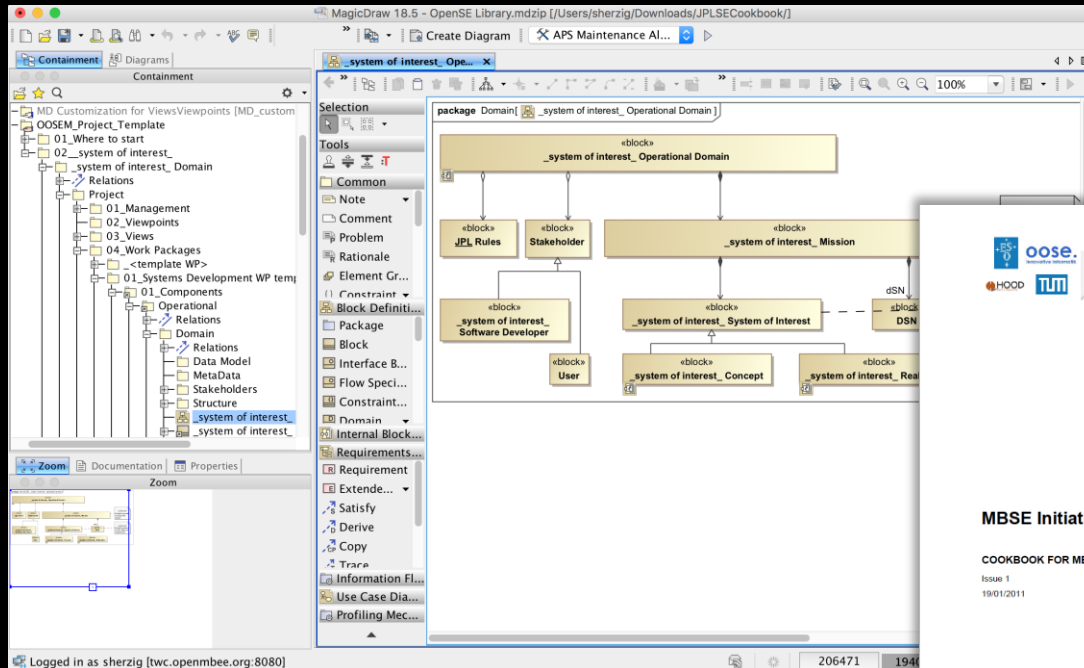
- Requirements Management
- Interface Management
- Design Management
- Trade Studies
- Interdisciplinary Integration
- Analysis Pipeline
- Resource Management
- Timeline Management

# OpenSE Cookbook combines different aspects

- Update 2012 “Cookbook for MBSE with SysML”
  - Focus on structure and requirements using European FP7 Active Phasing Experiment (APE) as case study
- Include Patterns developed for TMT
  - Focus on behavior and analysis workflows
- Guided by ESEM methodology
- Describe tooling support provided by JPL Systems Environment
- OpenSE model library provides commonly used elements
- Instructional examples
- Application to actual engineering team, i.e. TMT
- Template Models and recommended model organizations



# OpenSE Cookbook and Template Model



“Cookbook” for modeling methodology & patterns

The cover of the 'COOKBOOK FOR MBSE WITH SysML' features logos for oose, GSE, HOOD, and TUM. The title 'MBSE Initiative – SE2 Challenge' is prominently displayed, followed by 'COOKBOOK FOR MBSE WITH SysML', 'Issue 1', and the date '19/01/2011'.

This figure shows a detailed product tree for the ZEUS substructure. It starts with a root node 'ZEUS' and branches into various components like 'ZEUS-1', 'ZEUS-2', 'ZEUS-3', 'ZEUS-4', 'ZEUS-5', 'ZEUS-6', 'ZEUS-7', 'ZEUS-8', 'ZEUS-9', 'ZEUS-10', 'ZEUS-11', 'ZEUS-12', 'ZEUS-13', 'ZEUS-14', 'ZEUS-15', 'ZEUS-16', 'ZEUS-17', 'ZEUS-18', 'ZEUS-19', 'ZEUS-20', 'ZEUS-21', 'ZEUS-22', 'ZEUS-23', 'ZEUS-24', 'ZEUS-25', 'ZEUS-26', 'ZEUS-27', 'ZEUS-28', 'ZEUS-29', 'ZEUS-30', 'ZEUS-31', 'ZEUS-32', 'ZEUS-33', 'ZEUS-34', 'ZEUS-35', 'ZEUS-36', 'ZEUS-37', 'ZEUS-38', 'ZEUS-39', 'ZEUS-40', 'ZEUS-41', 'ZEUS-42', 'ZEUS-43', 'ZEUS-44', 'ZEUS-45', 'ZEUS-46', 'ZEUS-47', 'ZEUS-48', 'ZEUS-49', 'ZEUS-50', 'ZEUS-51', 'ZEUS-52', 'ZEUS-53', 'ZEUS-54', 'ZEUS-55', 'ZEUS-56', 'ZEUS-57', 'ZEUS-58', 'ZEUS-59', 'ZEUS-60', 'ZEUS-61', 'ZEUS-62', 'ZEUS-63', 'ZEUS-64', 'ZEUS-65', 'ZEUS-66', 'ZEUS-67', 'ZEUS-68', 'ZEUS-69', 'ZEUS-70', 'ZEUS-71', 'ZEUS-72', 'ZEUS-73', 'ZEUS-74', 'ZEUS-75', 'ZEUS-76', 'ZEUS-77', 'ZEUS-78', 'ZEUS-79', 'ZEUS-80', 'ZEUS-81', 'ZEUS-82', 'ZEUS-83', 'ZEUS-84', 'ZEUS-85', 'ZEUS-86', 'ZEUS-87', 'ZEUS-88', 'ZEUS-89', 'ZEUS-90', 'ZEUS-91', 'ZEUS-92', 'ZEUS-93', 'ZEUS-94', 'ZEUS-95', 'ZEUS-96', 'ZEUS-97', 'ZEUS-98', 'ZEUS-99', 'ZEUS-100'. The tree is accompanied by a photograph of the ZEUS sensor hardware.

**Figure 5 Product Tree of the ZEUS substructure**

ZEUS is one of the evaluated planning sensors (Figure 5) and is based on the modified Mach-Zehnder interferometer phasing sensor. It is mounted on a breadboard and consists of a shutter, a cover, a color filter wheel, a neutral density filter wheel, and a translation stage which carries a phase mask. Different phase masks can be moved to the focal position by means of a translation stage, able to move in the X and Y directions.

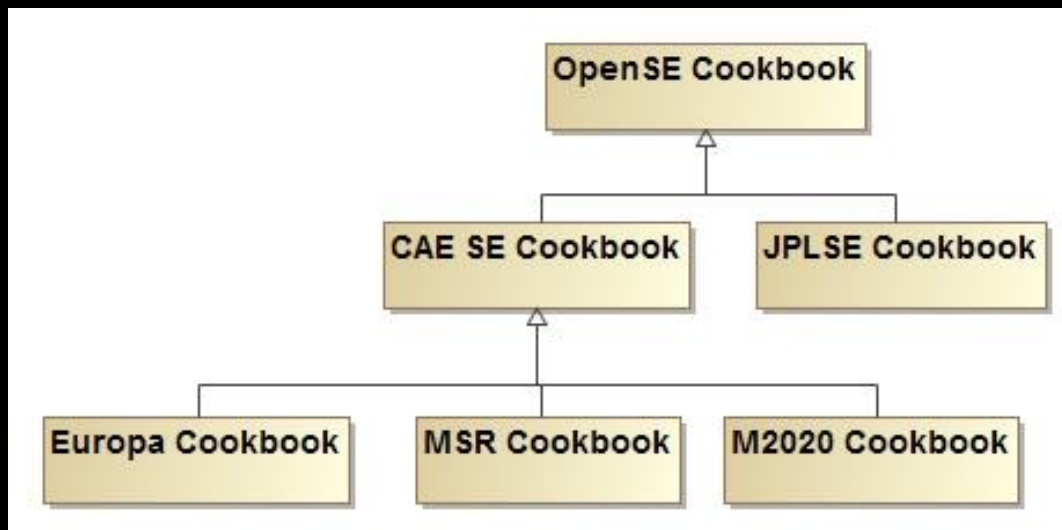
The two filter wheels located after the phase mask translation stage:

- A neutral Density Filter wheel: a set of 8 different neutral density filters are available
- An optical filter wheel: a set of 8 different optical filters centered on different wavelengths and with different bandwidths are available

Template models to be used by projects as a starting point, with recommended organization, model libraries, etc.

# OpenSE Cookbook promotes re-use

- OpenSE Cookbook contributes to JPL institutional and project specific Cookbooks
- Project-independent modeling patterns as guidelines
- Project-specific modeling patterns for common modeling tasks



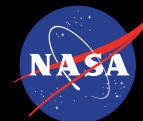
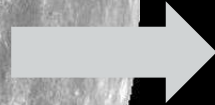
# OpenSE Cookbook is used as reference

- OpenSE cookbook and TMT model used as reference model for the OMG SysML 2 standard
  - Demonstrate how SysML 2 will improve, simplify, change model wrt SysML 1.x
- Training material and knowledge transfer
- Promote standards and conventions
- Used by vendors as reference to test and evolve products



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# Systems Model is developed according to ESEM using Cookbook Patterns

- Define APS Mission boundaries
- Elaborate Conceptual Architecture
- Capture Component Behavior and Characteristics
- Specify Interactions between Components
- Run Analyses

# Define APS Mission boundaries

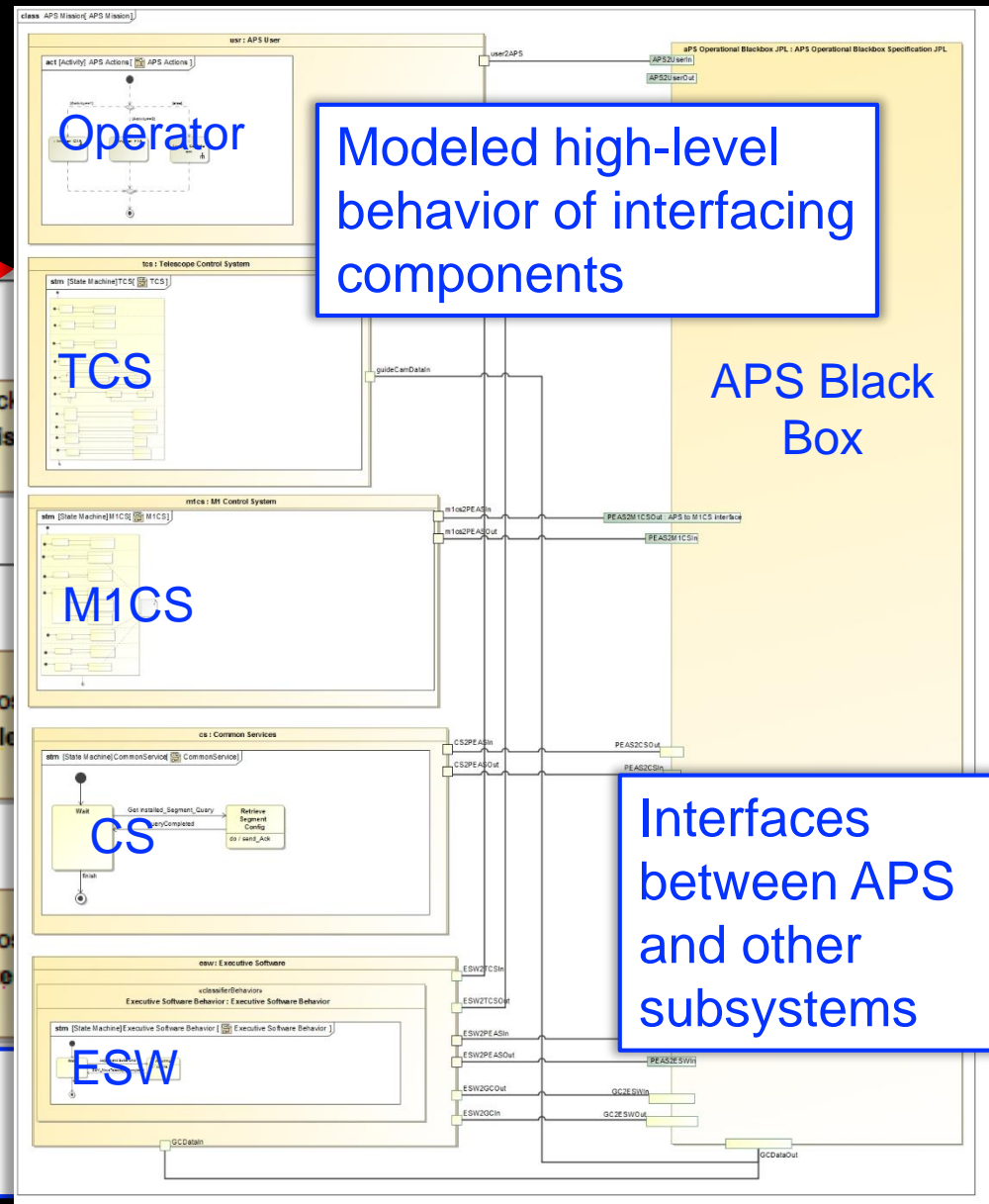
TMT specification handed to JPL

«block»  
APS Black Box Specification TMT

«block»  
APS Operational Blackbox Specification JPL

JPL realization of APS

Other TMT Subsystems



# Elaborate Conceptual Architecture

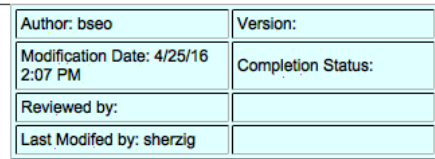
APS conceptual is broken down into several components

Procedure Executive Analysis Software (PEAS)

SH  
Camera

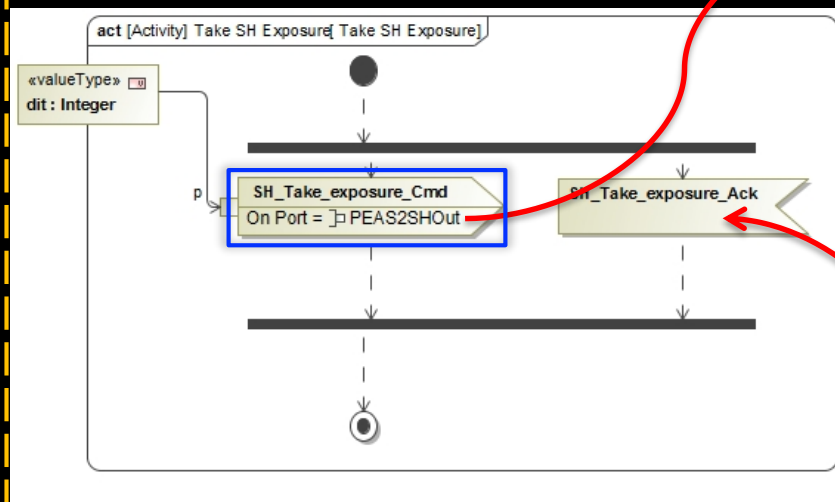
Behavior of all interacting components modeled

Operational  
behavior  
captured with state  
machines and  
activity models



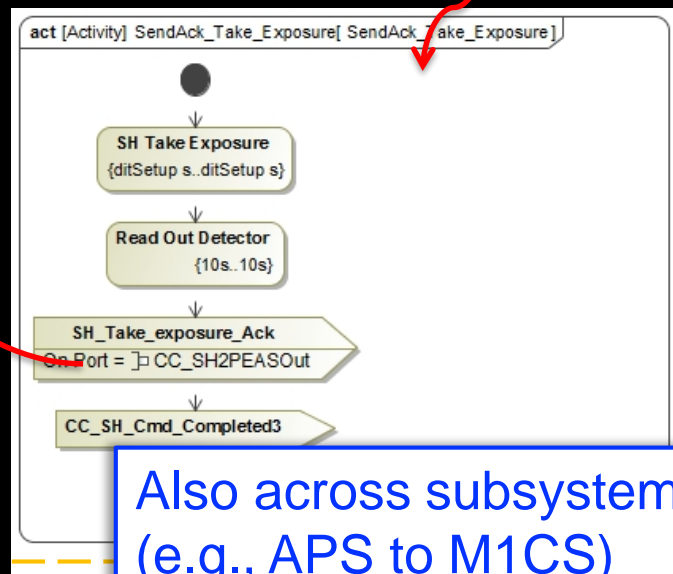
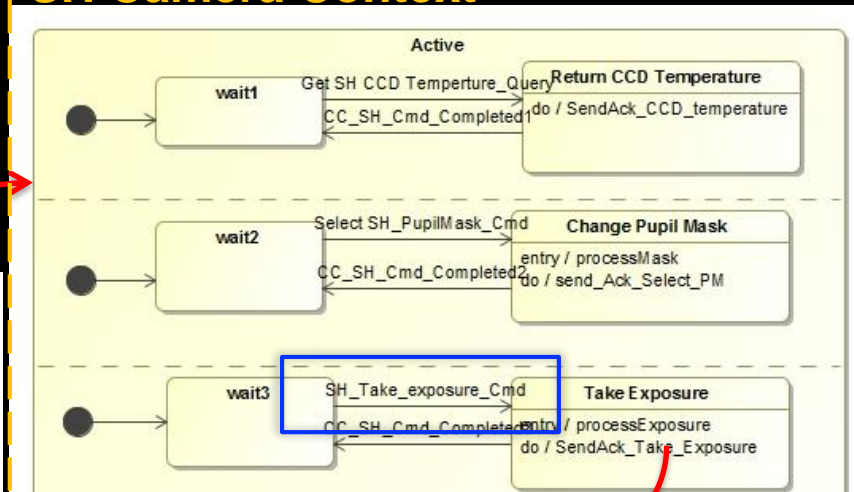
# Specify Interactions Between Components

## PEAS Context



Use of signals sent over ports to simulate a message passing mechanism between components

## SH Camera Context

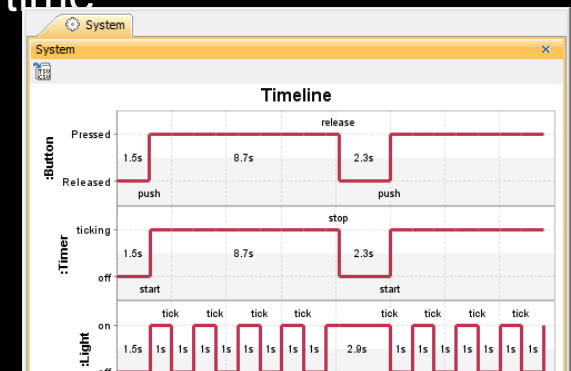
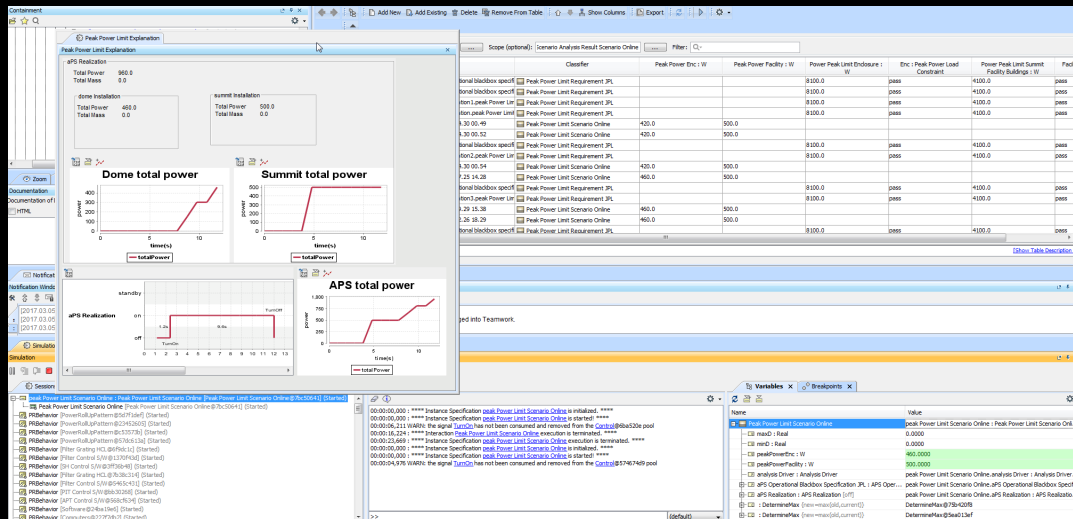


Also across subsystems!  
(e.g., APS to M1CS)



# Run Analyses

- Run a configured analysis with a simulation engine on the initial conditions to get the final conditions
- Produce the analyses declaratively, repeatably (in any system), without a single line of project-specific code -> reducing time and resources
- Produce the following views on final conditions
  - **Table** showing final analysis values (e.g. peak power) and the constraint's pass/fail status for each scenario
  - **Timelines**: state changes for components over time
  - **Value profiles**: total rolled up values over time

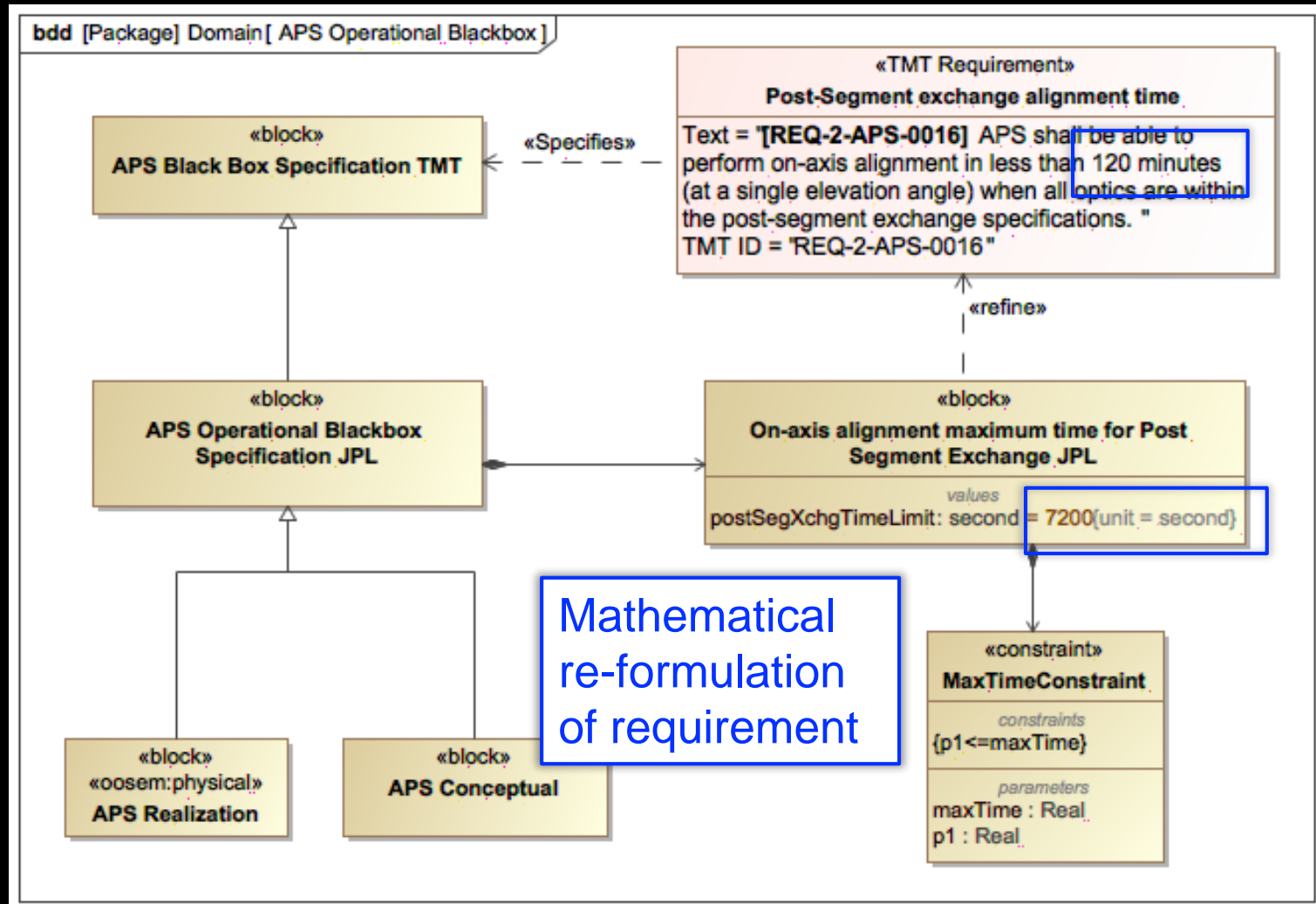


#	Name	Classifier	T Final : Real	Ph
1	calibrations Duration S	Calibrations Duration S		
2	calibrations Duration S	APS Conceptual		
3	calibrations Duration S	Procedure Executive an	8466.0	11

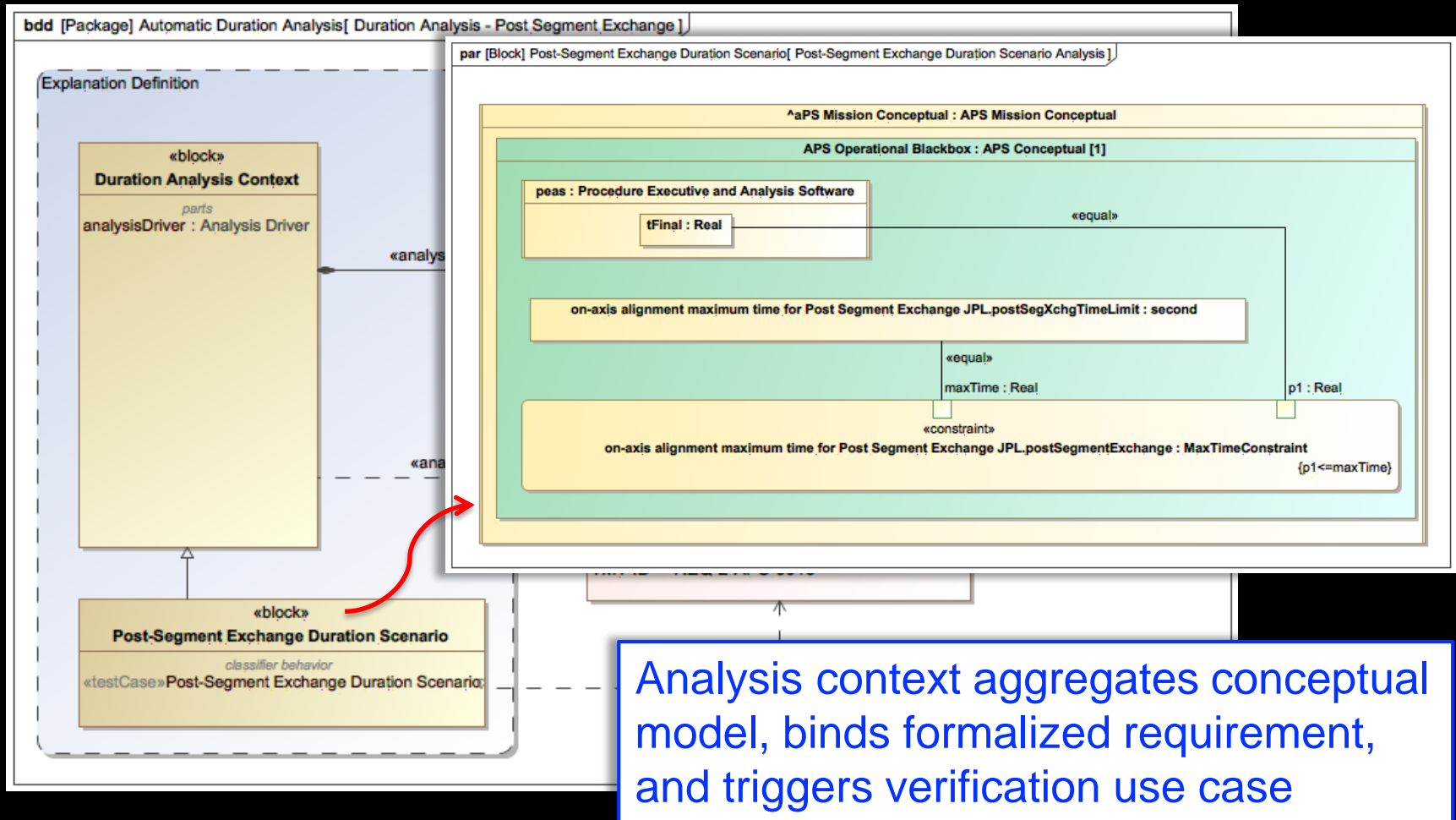
# Requirements Verification

- Intent
  - Validate requirements, verify as designed system against requirements and publish analysis results
- Cookbook Volume
  - System Requirements Management
- Educational example
  - Autonomous Ferry Transportation
- Known Uses
  - APS - Post-segment exchange timing requirements
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor
- Notes
  - Property Based Requirements links Requirements Management and System Design

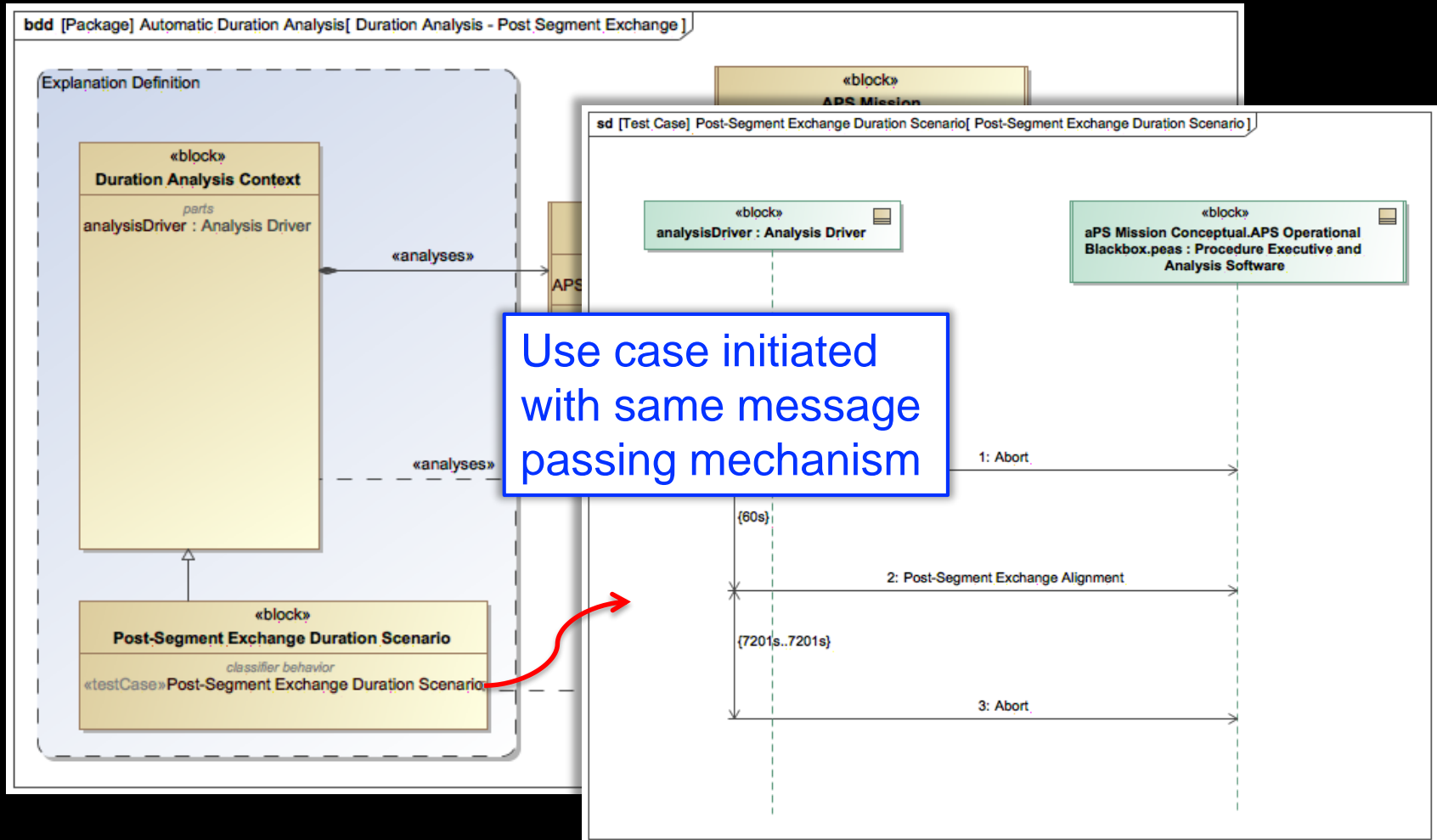
# Formalizing Requirements with Property Based requirements



# Verifying Timing Requirements by Simulation

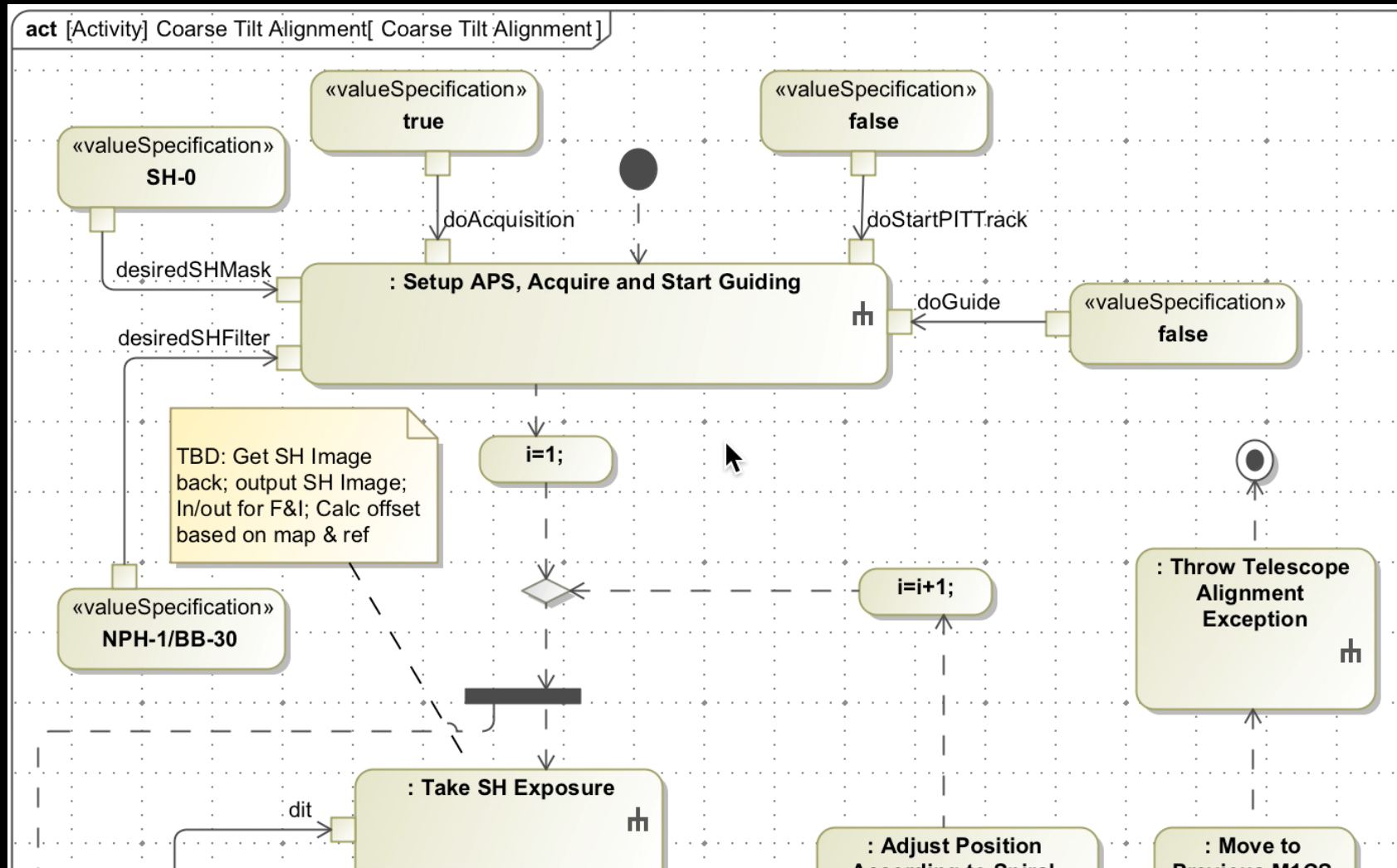


# Verifying Timing Requirements by Simulation

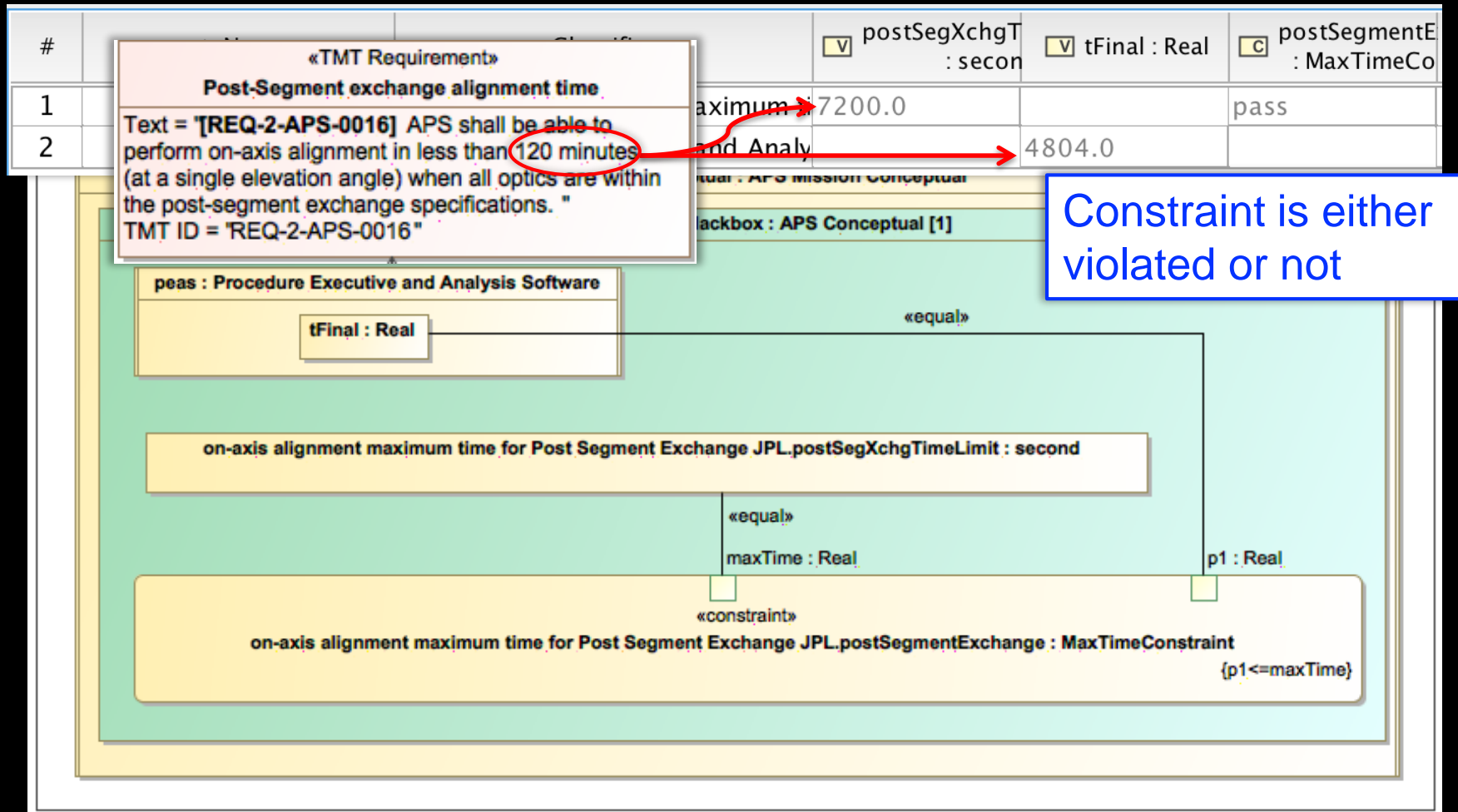




# Verifying Timing Requirements by Simulation



# Verifying Timing Requirements by Simulation



# Monte Carlo driven Analysis

- Intent
  - Estimate the characteristics and probability of a particular behavior using modeling anchored through data.
- Cookbook Volume
  - System Analysis Management
- Educational example
  - Quadrupedal Robot
- Known Uses
  - AO - Acquire a target with IRIS and NFIRAOS
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor
- Notes
  - SysML probability concepts and distributed properties capture operational knowledge in system model

# Error Budget Management

- Intent
  - Manage error budgets of technical resources such as Mass, Power, Data
- Cookbook Volume
  - System Resource Management
- Educational example
  - Microscope
- Known Uses
  - APS - Alignment error of the M3 to APS interface
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor

## Conclusions and Summary

- OpenSE Cookbook addresses SE concerns
- Built on proven patterns from TMT and APE
- Supported by tooling



# Acknowledgements

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# References

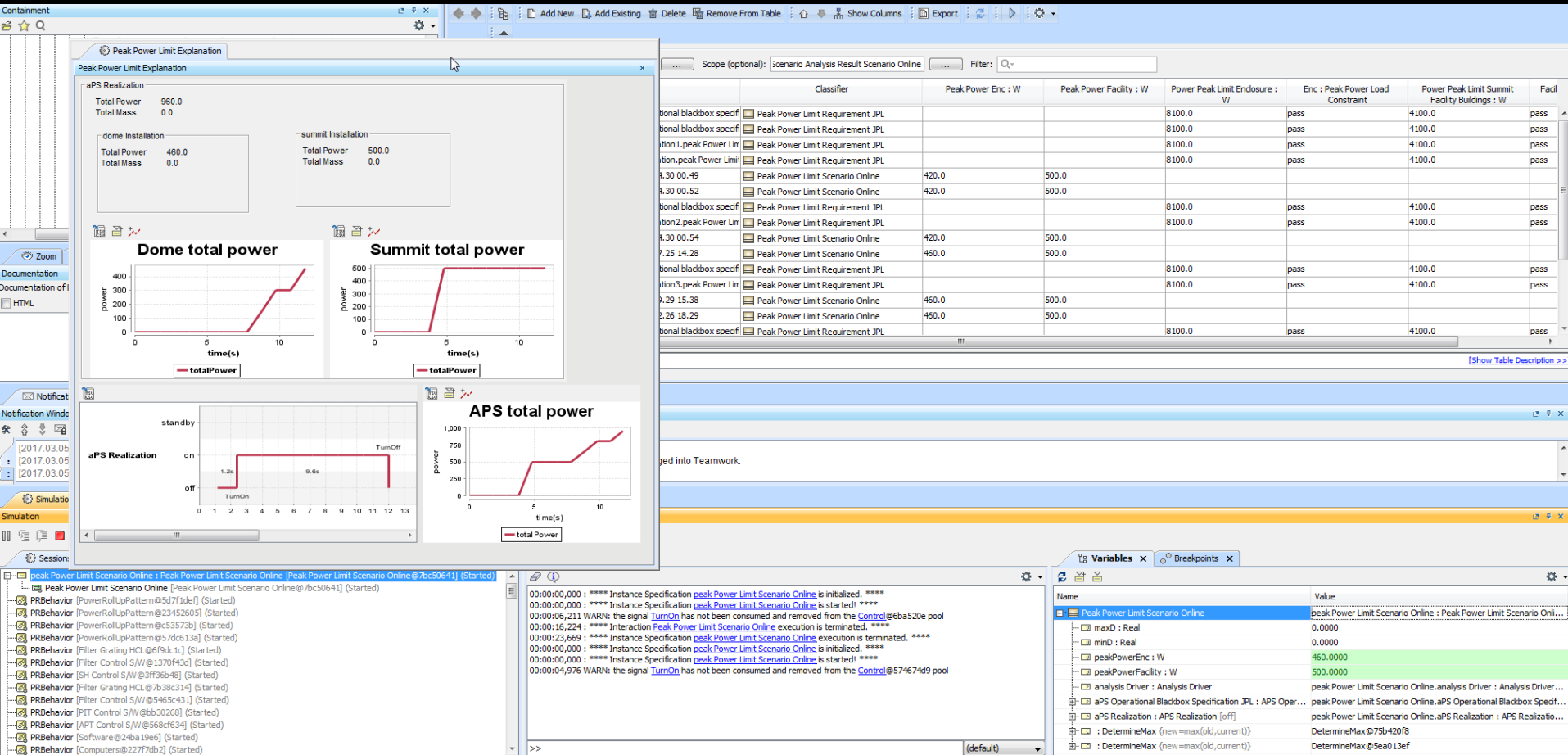
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- OpenSE Cookbook: <https://mms.openmbee.org>
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- Open Source TMT model: <https://github.com/Open-MBEE/TMT-SysML-Model>
- Open Source Engineering Environment: <https://www.openmbee.org>
- Docgen, View&ViewPoints: <https://github.com/Open-MBEE/mdk/tree/mdk-manual/src/main/dist/manual>
- JPL Model-Based Systems Engineering Case Study:  
[http://omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:incose\\_mbse\\_iw\\_2017:iw\\_2017\\_open\\_mbee.pdf](http://omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:incose_mbse_iw_2017:iw_2017_open_mbee.pdf)
- A Practical Guide to SysML, 3<sup>rd</sup> Edition, Chapter 17 by Friedenthal, Moore, and Steiner
- Zwemer, D., “Connecting SysML with PLM/ALM, CAD, Simulation, Requirements, and Project Management Tools”, May 2016
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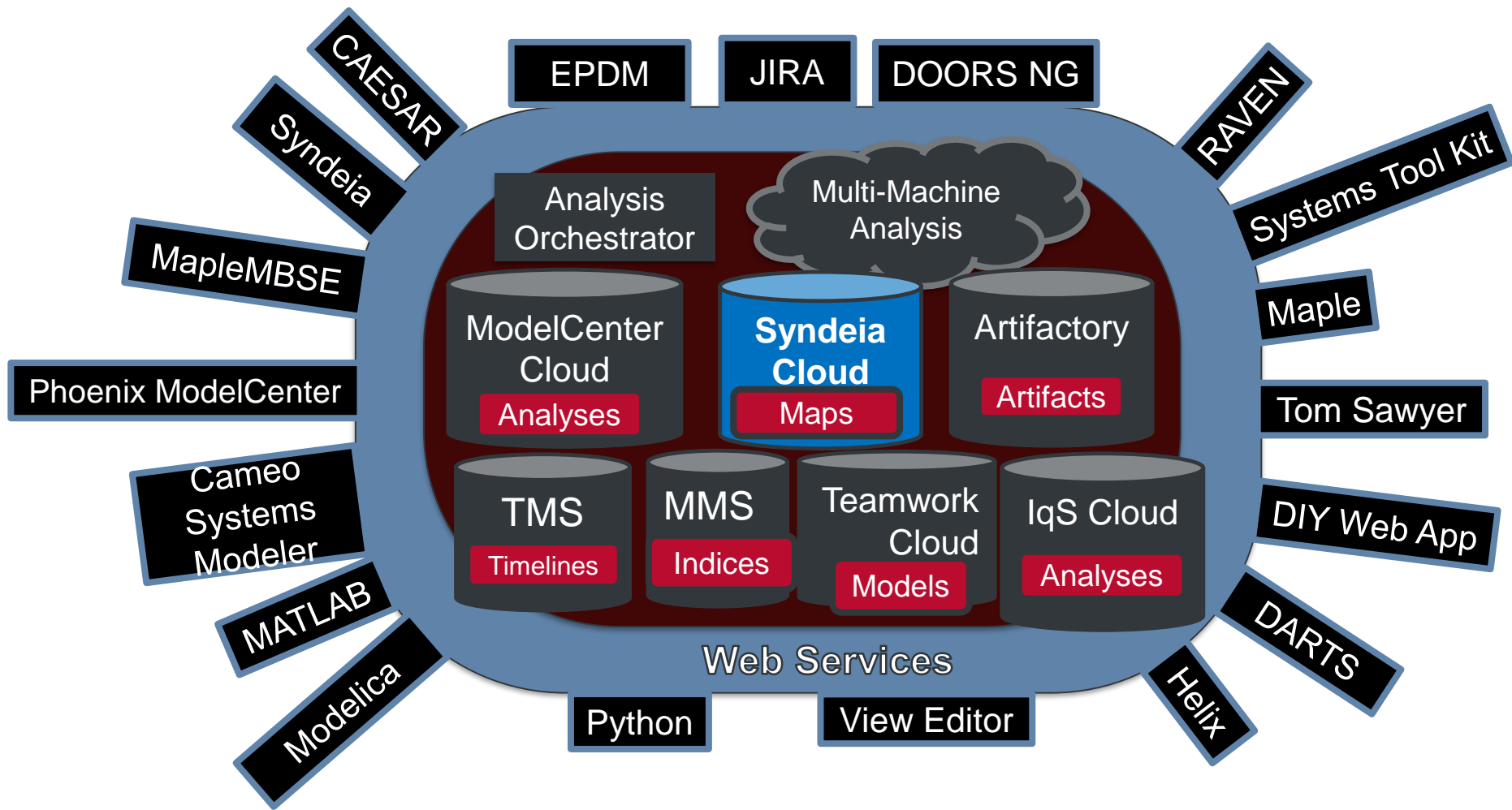
The background of the slide is a composite image of space. On the left side, there is a large, bright, swirling structure resembling an accretion disk or a nebula, with colors ranging from deep red to bright white. On the right side, the background is a dark, starry field with a prominent horizontal band of stars, likely representing the Milky Way galaxy. The text "BACKUP SLIDES" is centered in the upper half of the image, written in a bold, red, sans-serif font.

**BACKUP SLIDES**



# Power Analysis





OpenCAE DevOps